Cost-Effective In-Situ PHC/VOC Remediation

Biostimulation as a Residual Source Mass Remediation Strategy

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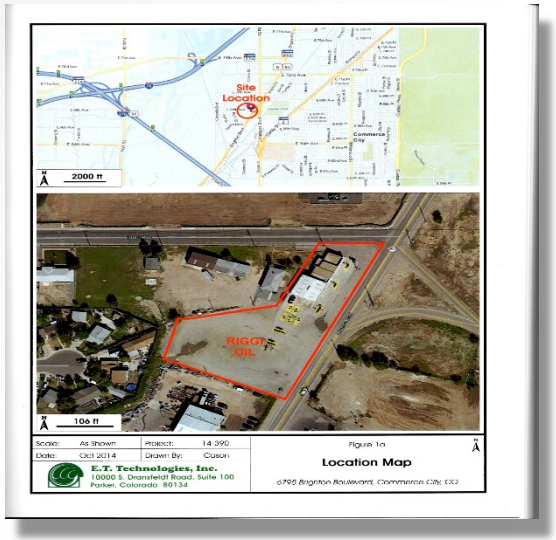
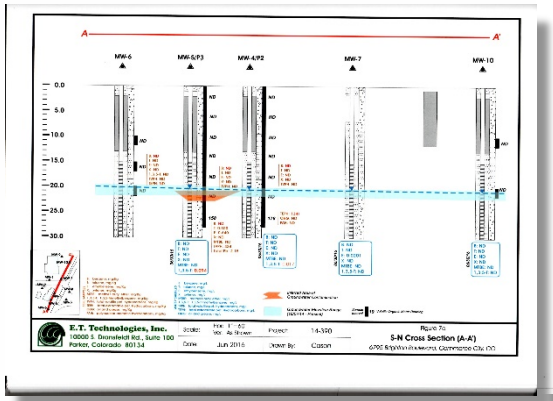
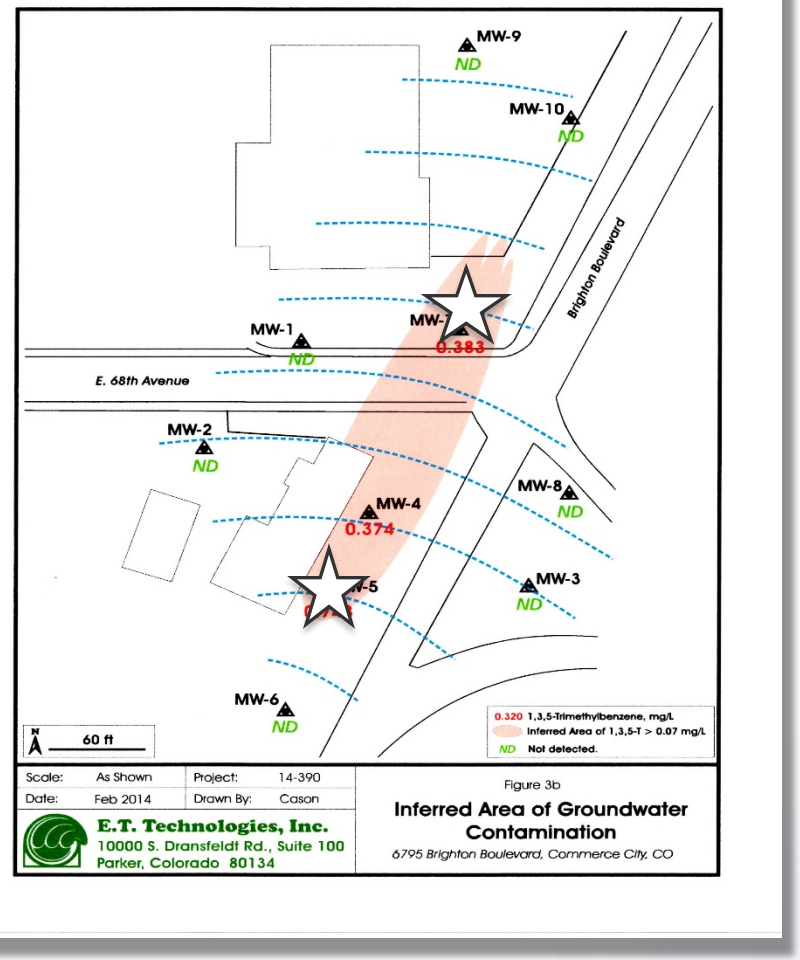
Safe Sustainable Effective

Parker Colorado – Bulk Tank Storage Facility
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

- Bulk fuel supply facility with underground storage tanks (USTs) containing petroleum hydrocarbon (PHC) products since 1960s
- Site characterization documented soils above water table within allowable State of Colorado risk-based screening levels (RBSLs); however,
- Concentrations of 1,3,5-Trimethylbenzene ([1,3,5-TMB]) were detected in groundwater above the allowable [70.0 µg/L]
- February 2014 plume extended ≈270-ft from source area (MW5) downgradient and inclusive of monitoring location MW7







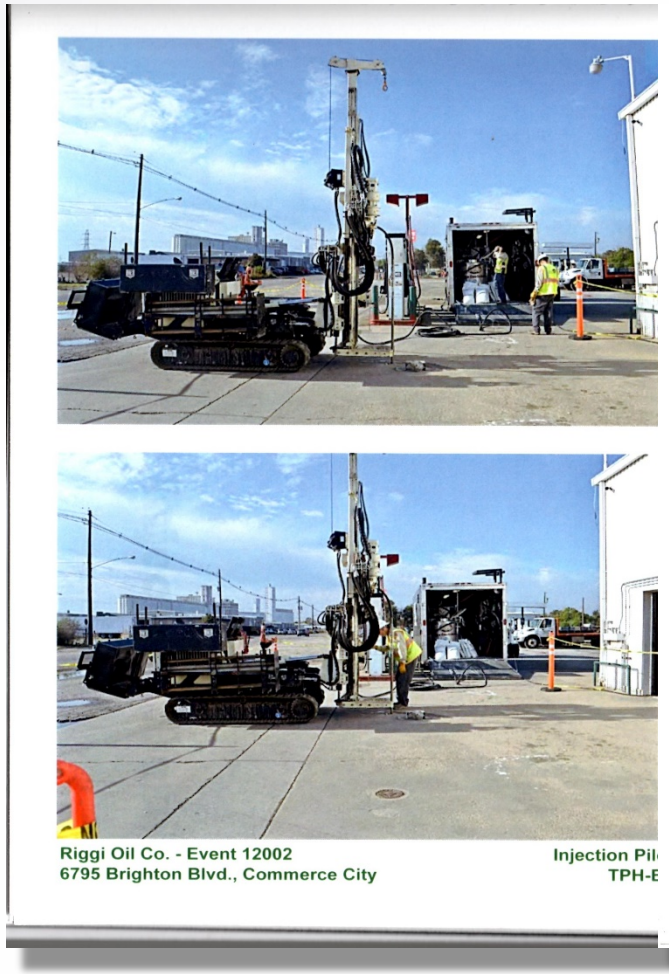
Parker Colorado – Site Characteristics
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

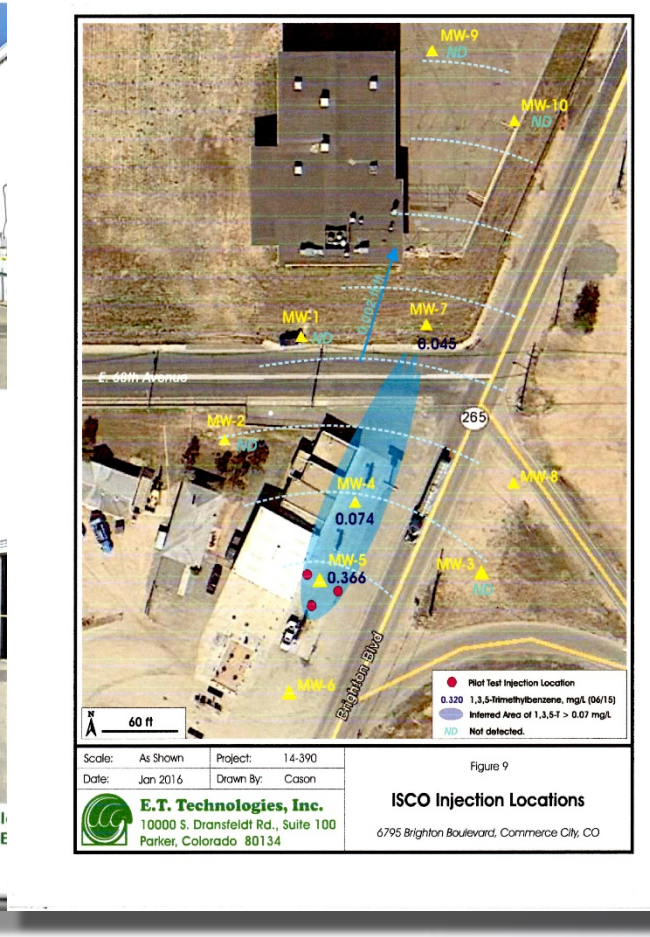
Colorado Division of Oil and Public Safety (OPS) approved in-situ biostimulation evaluation using TPHENHANCED™ to determine:

1) ability of TPHENHANCED™ to provide nutrients and enhance growth of native heterotrophic petrophylic bacteria

2) ability of TPHENHANCED™ to sustainably provide an analogue to Oxygen (O_2) and support microbial respiration

3) ability of TPHENHANCED™ to cost-effectively enhance non-assimilatory biodegradation of [1,3,5-TMB]





How is Biostimulation Cost-Effective?

Biostimulation; a proven remediation strategy that:

- Nourishes and stimulates *native* microbial populations
- Enhances heterotrophic bacteria growth and consumption
- Expedites solubilization of residual source mass contaminants
- Increasing contaminant bioavailability
- Enhances dissolve phase contaminant destruction to
- Realize Long-Term Compliance

Lower-Carbon Footprint; minimize impacts of remediation:

- Supports Passive Amendment Deployment Strategies
- Reduces [Methane] - Indoor Ambient Air Concerns - Safe
- Minimizes Source Removal Activities, Fuel and Energy Costs
- Minimize-Eliminate Nuisance Noise, Emissions and Vapors

Pro's and Con's of Bioremediation

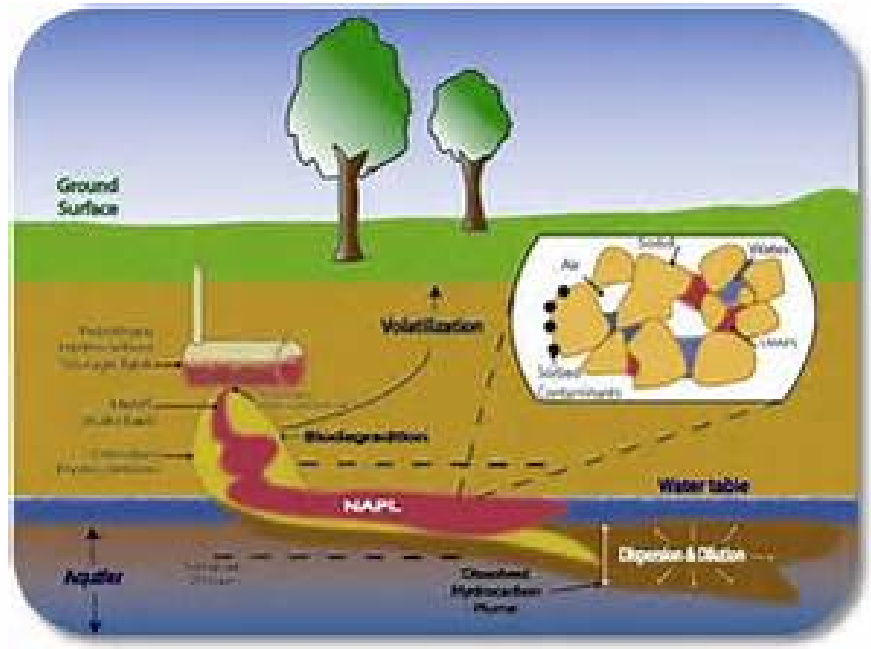
When is biostimulation a cost-effective remedial strategy?

- Inappropriate without Physical Removal
  - Pooled DNAPL Source Zone (non-residual source mass)
  - Remediation timeframe is of the essence

- Appropriate with Remedial Design Considerations
  - Subsurface non-homogenous
  - Tight silty/clay soil with low effective porosity
  - Residual DNAPL; co-mingled contaminants
  - Fractured bedrock
  - Highly aerobic formation
  - Planned future site disturbance

- Ideal Situation
  - Accessible impact zone with anaerobic overburden
  - Homogeneous Stratigraphic Conditions
  - Ex-Situ Biopiles

Sorry! We Cant Help You Here



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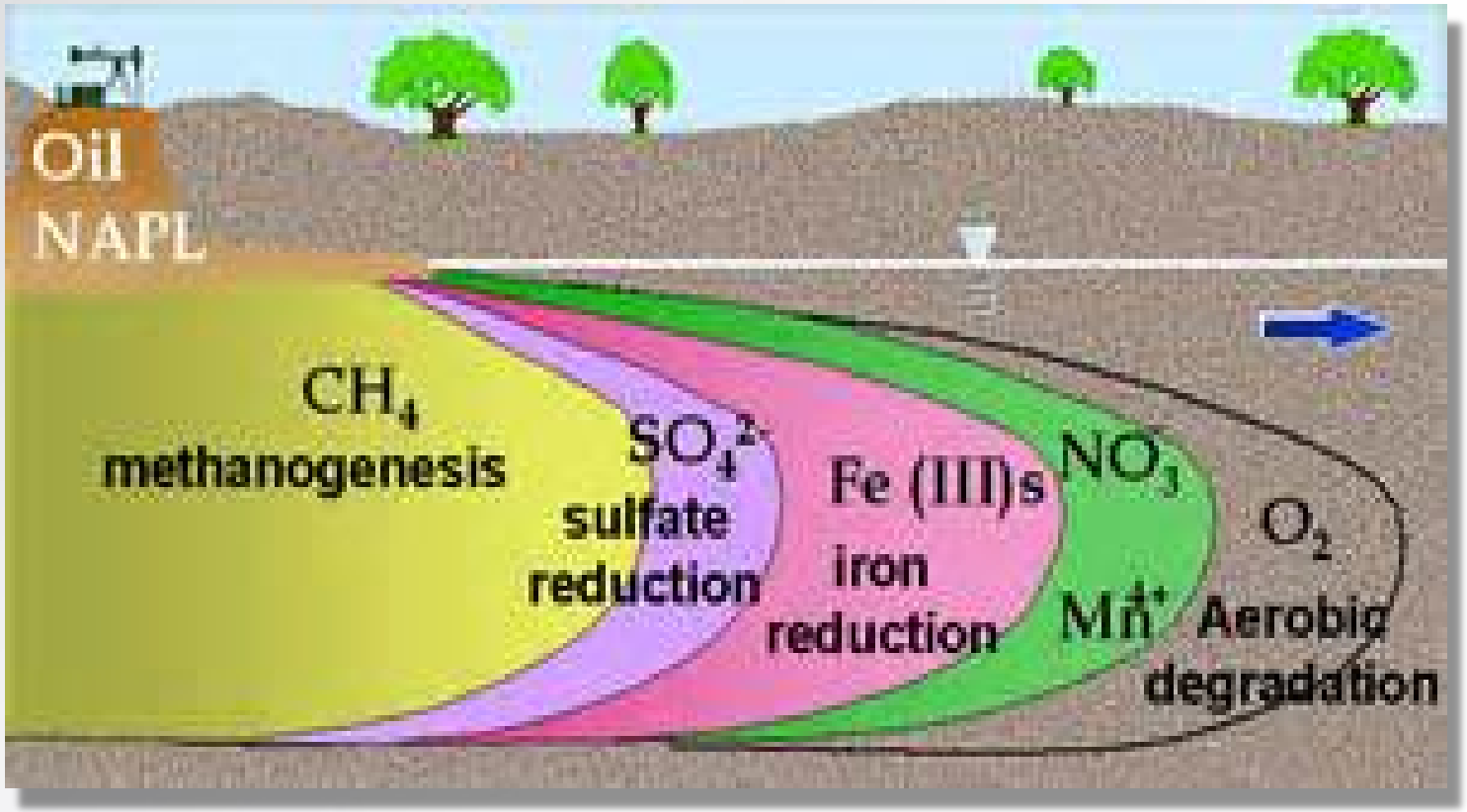
The Geochemistry of a PHC Spill



Source area methanogenic
- Oxygen Depleted
- Electron Acceptor Depleted

Leading Edge of Plume
- Oxygen Rich
- Contaminant Used as Donor

Petrophylic bacteria bummed
- Tons of food
- Cant breathe!

Aerobic Conditions

TPHenhanced™

Alternative to O_2 plus proprietary macro-micro nutrient formulation allowing respiration under anaerobic conditions

Provide Alternative Respiratory Pathways for Native Heterotrophic Microbial Populations

Nitrate Reduction/Respiration

NO_3^- (+5) → NO_2^- (+3) → NO (+2) → N_2O (+1) → N_2

Increase ORP

Enhance the Utilization of Naturally Occurring Respiratory Pathway Sources

Manganese/Iron(III) Reduction/Respiration

$Mn^{4+} \rightarrow Mn^{2+}$

$Fe^{3+} \rightarrow Fe^{2+}$

Sulfate Reduction/Respiration

$SO_4^{2} \rightarrow H_2S$ ↑

Methanogenic Conditions

Little to No Biotic Activity

Electron Donor

PHC, VOC, sVOC Contaminants

Low-Cost Low-Impact Safe Effective Sustainable

Proprietary Formulation of Macro-Micro Nutrients

Alternative Respiratory Sources to Oxygen (O_2)

Facilitates Non-Assimilatory Destruction of Petroleum Hydrocarbons

Volatile and Non-Volatile Organic Contaminants (VOC/sVOC/PHCs)

Safe, Sustainable

Enhances Native Microbial Populations

Maintains Anaerobic Conditions created by Contaminant

Raises Treatment Zone Oxygen Reduction Potential (ORP)

Reduces Production of [Methane]

Allows *Native* Heterotrophic Bacteria to Assimilate Available Anthropogenic Carbon Source

Expedites Solubilization of Residual Source Mass

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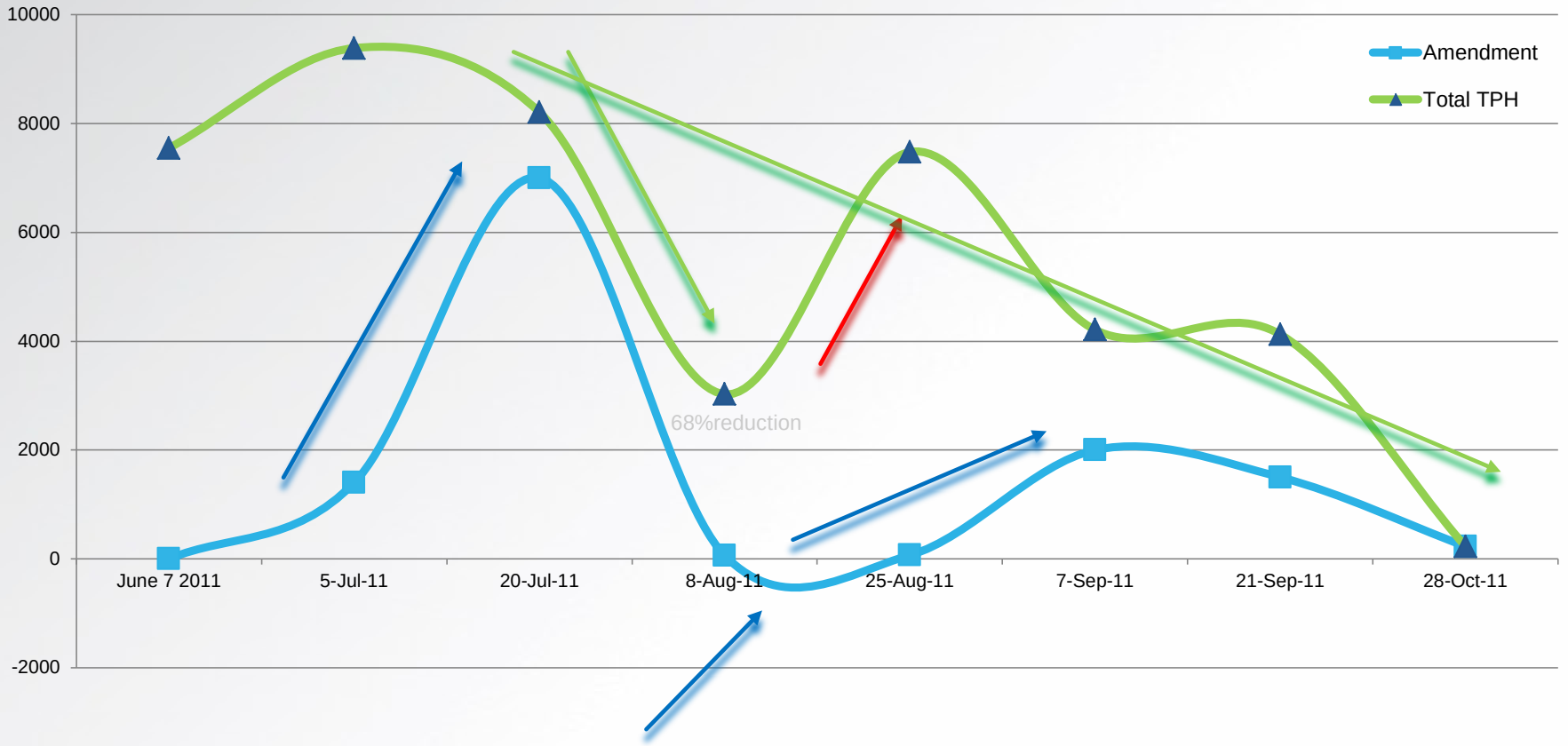
TPHENHANCED™

Maine DEP – Searsport Pipeline
Argyle Pump Station



Increase Additive Availability

Enhance Microbial Respiration

Expedite Dissolve Phase Contaminant Assimilation

Exhaust Additive Availability

Return to Methanogenic Conditions; No Biotic Activity

Rebound

Provide More Additive

Re-establish elevated ORP

Realize 97% Reduction [PHC]
Passive Aggressive Destruction

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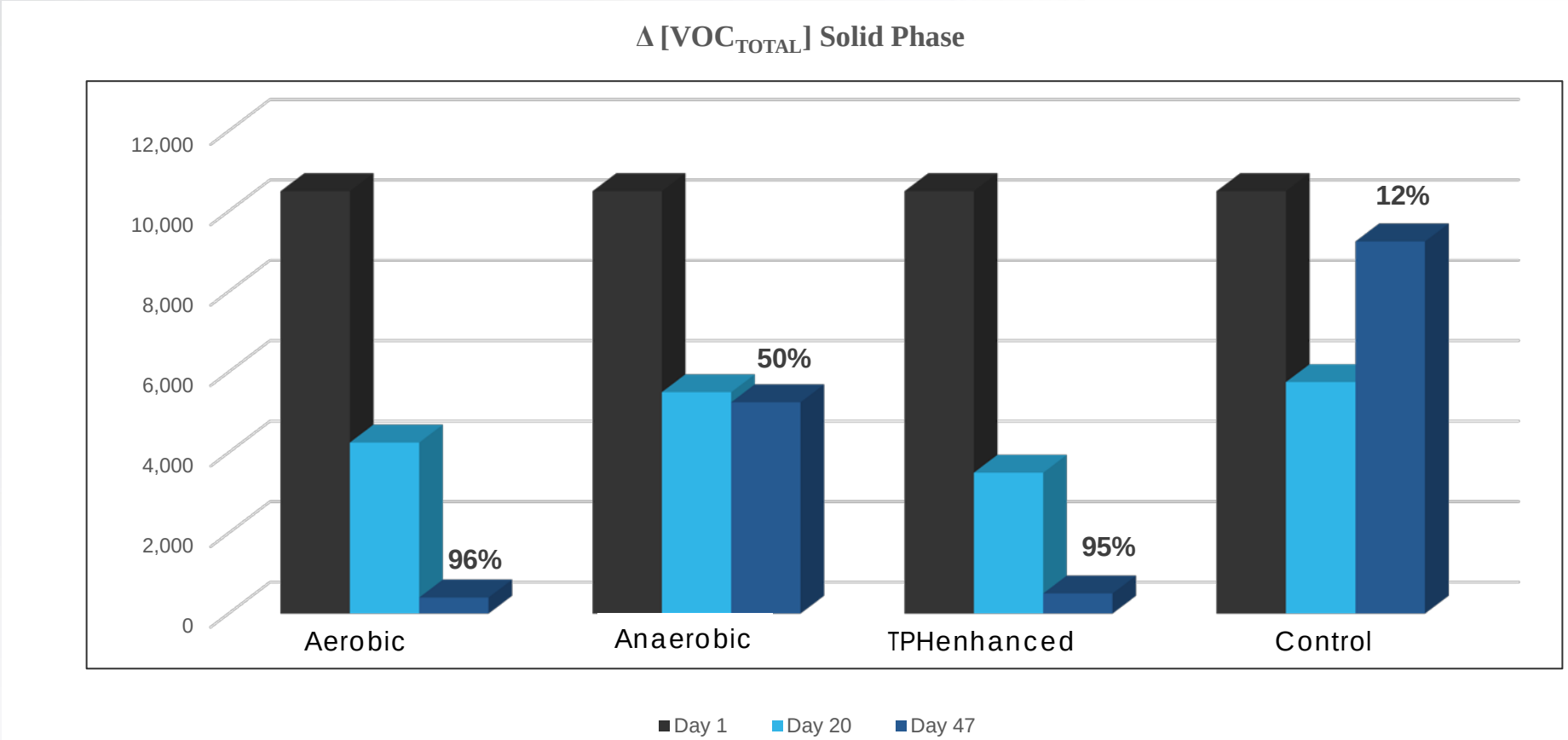
Microcosm Study Comparing Various Aerobic/Anaerobic Strategies



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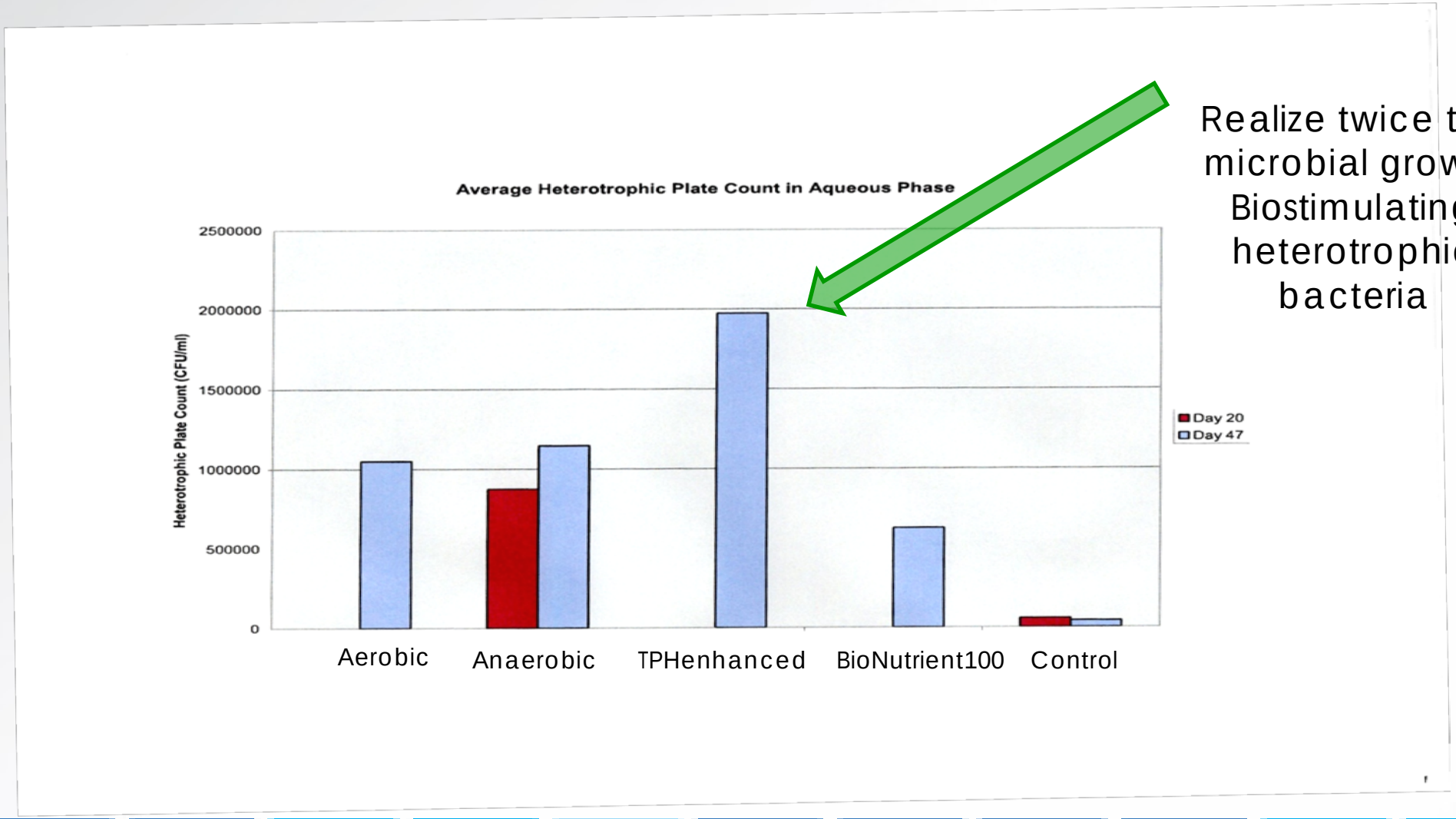

Realize twice the microbial growth Biostimulating heterotrophic bacteria

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TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

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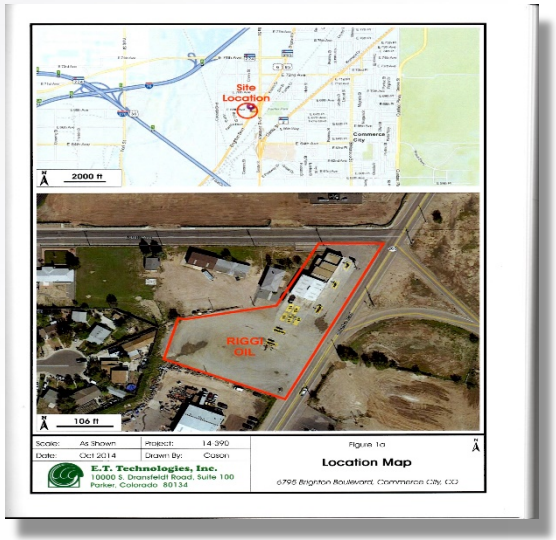
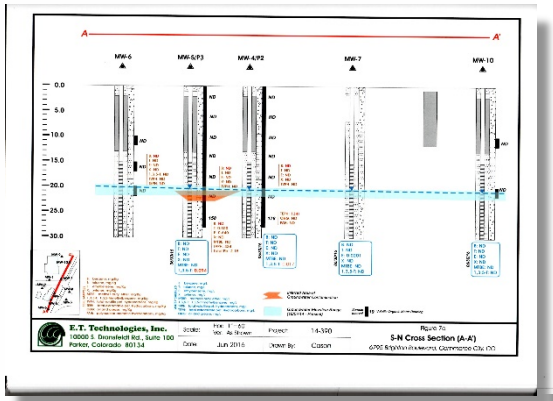
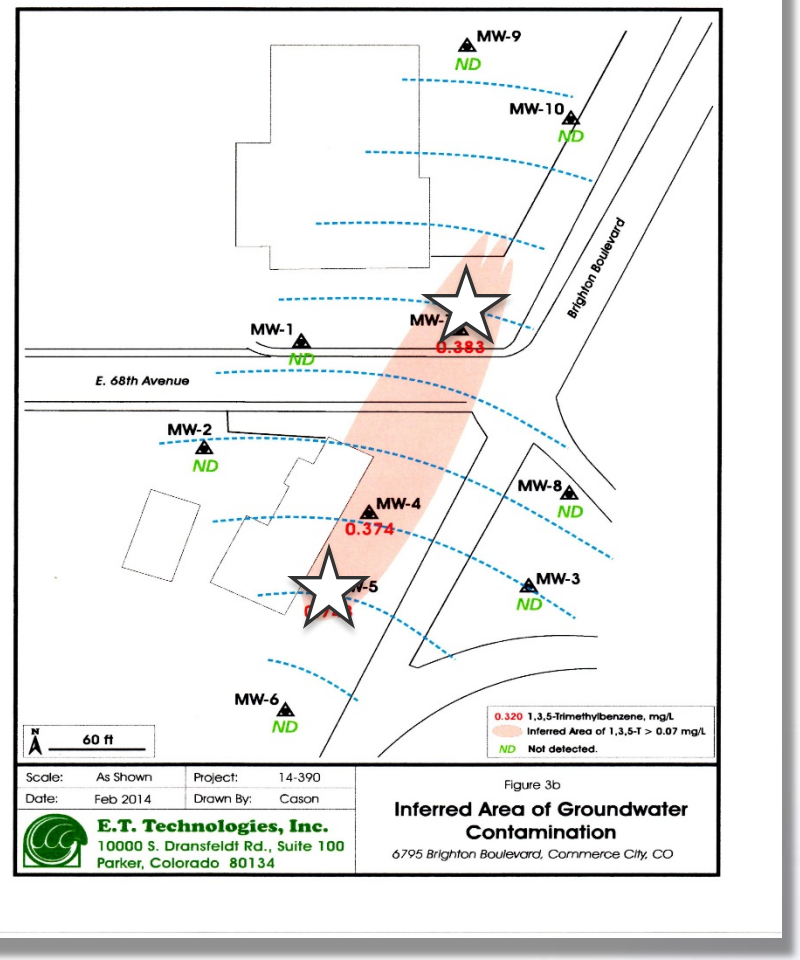


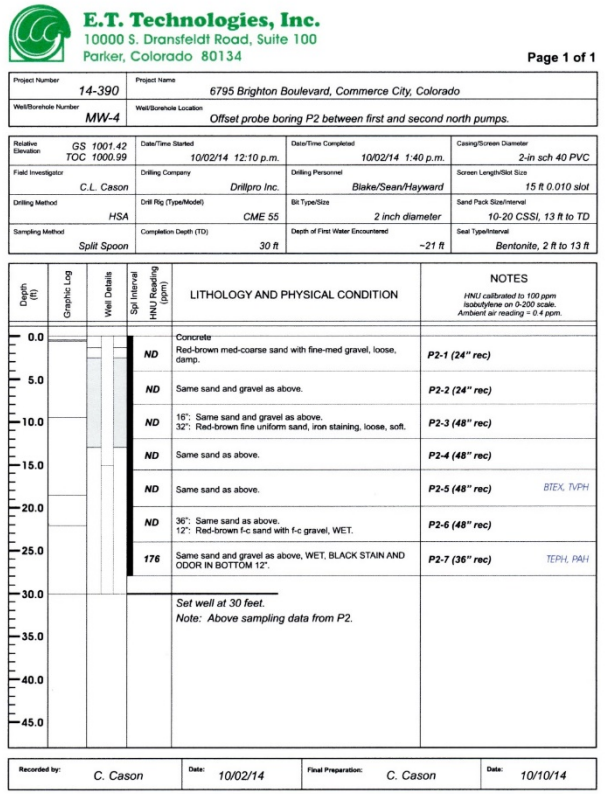




Parker Colorado – Site Characteristics
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

- Soils described red-brown med-coarse sand with fine-med gravel.
- Loose & damp from 0-30ft bgs.
- Wet soils, staining, odor from ≈20-30ft bgs.

- Plume extends laterally ≈60ft
- Impact estimated ≈10 to 15-ft vertically.



E.T. Technologies, Inc.
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Parker, Colorado 80134

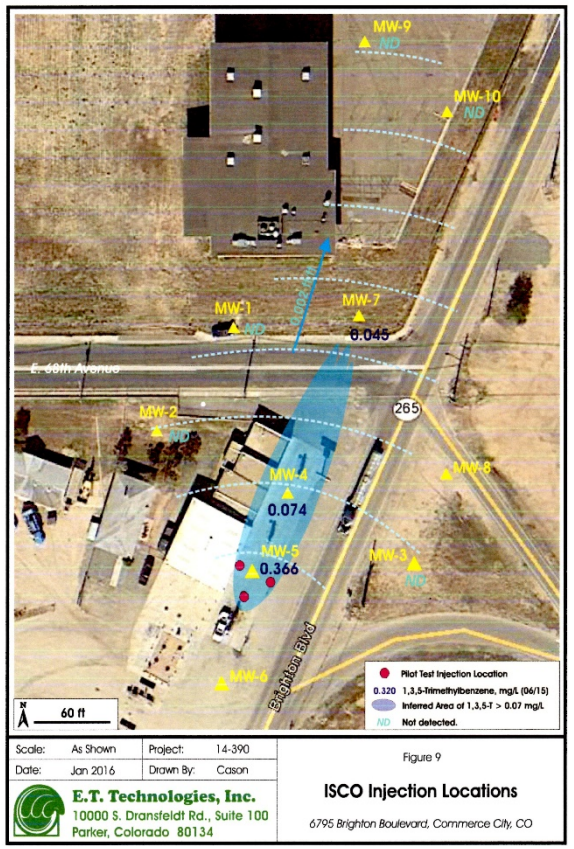
Page 1 of 1

Project Number: 14-390	Project Name: 6795 Brighton Boulevard, Commerce City, Colorado
Well/Borehole Number: MW-4	Well/Borehole Location: Offset probe boring P2 between first and second north pumps.

Relative Elevation: GS 1001.42 TOC 1000.99	Date/Time Started: 10/02/14 12:10 p.m.	Date/Time Completed: 10/02/14 1:40 p.m.	Casing/Screen Diameter: 2-in sch 40 PVC
Field Investigator: C.L. Cason	Drilling Company: Drillpro Inc.	Drilling Personnel: Blake/Sean/Hayward	Screen Length/Slot Size: 15 ft 0.010 slot
Drilling Method: HSA	Drill Rig (Type/Model): CME 55	Bit Type/Size: 2 inch diameter	Sand Pack Size/Interval: 10-20 CSSI, 13 ft to TD
Sampling Method: Split Spoon	Completion Depth (TD): 30 ft	Depth of First Water Encountered: ~21 ft	Seal Type/Interval: Bentonite, 2 ft to 13 ft

Depth (ft)	Graphic Log	Well Details	Spl Interval	HNU Reading (ppm)	LITHOLOGY AND PHYSICAL CONDITION	NOTES (HNU calibrated to 100 ppm isobutylene on 0-200 scale. Ambient air reading = 0.4 ppm.)	
0.0					Concrete		
				ND	Red-brown med-coarse sand with fine-med gravel, loose, damp.	P2-1 (24" rec)	
5.0				ND	Same sand and gravel as above.	P2-2 (24" rec)	
10.0				ND	16": Same sand and gravel as above. 32": Red-brown fine uniform sand, iron staining, loose, soft.	P2-3 (48" rec)	
15.0				ND	Same sand as above.	P2-4 (48" rec)	
				ND	Same sand as above.	P2-5 (48" rec)	BTEX, TVPH
20.0				ND	36": Same sand as above. 12": Red-brown f-c sand with f-c gravel, WET.	P2-6 (48" rec)	
25.0				176	Same sand and gravel as above, WET, BLACK STAIN AND ODOR IN BOTTOM 12".	P2-7 (36" rec)	TEPH, PAH
30.0					Set well at 30 feet. Note: Above sampling data from P2.		
35.0							
40.0							
45.0							

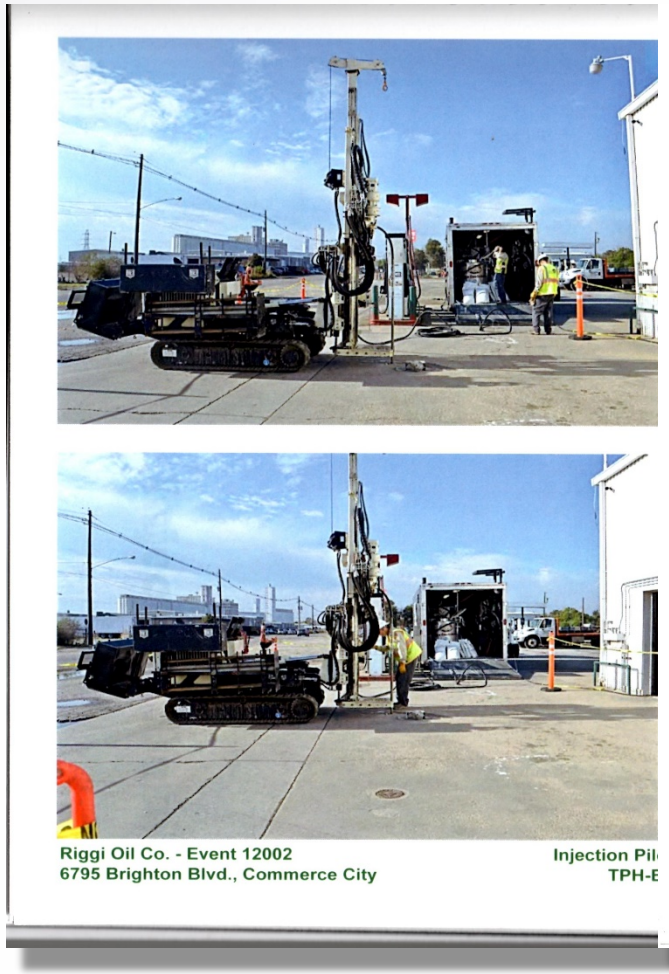
Recorded by: C. Cason	Date: 10/02/14	Final Preparation: C. Cason	Date: 10/10/14

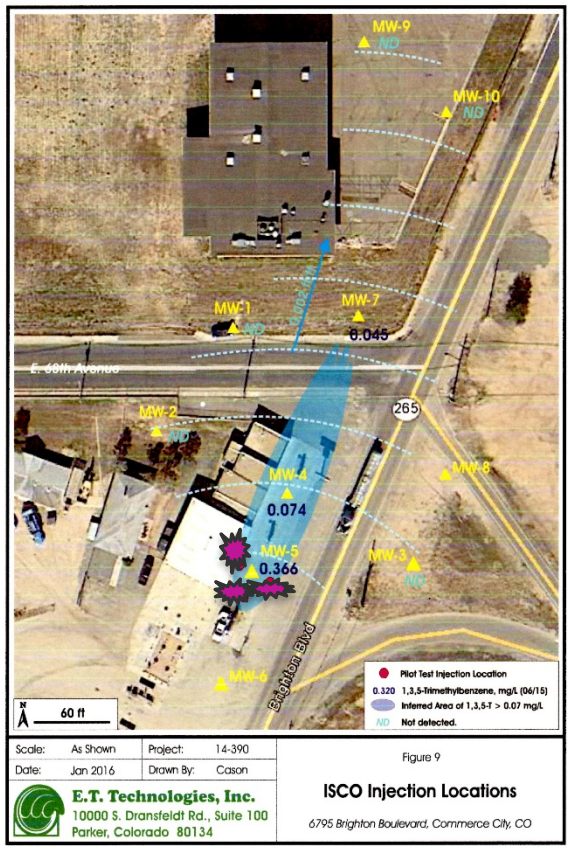


Parker Colorado – Remedial Strategy - Approach
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

- Sept. 28, 2015 additive deployed via GeoProbe
- DT7822 direct push 'Vista Clean Inject' system and tooling.

- Target amendment depth 18ft to 28ft bgs
- Two-foot intervals to vertically distribute TPHENHANCED™
- 3 nodes advanced ≈15ft from source well MW5
  - one up-gradient
  - two cross-gradient
- 160 pounds TPHENHANCED™ with 230-gallons water injected per node (3.82% slurry)





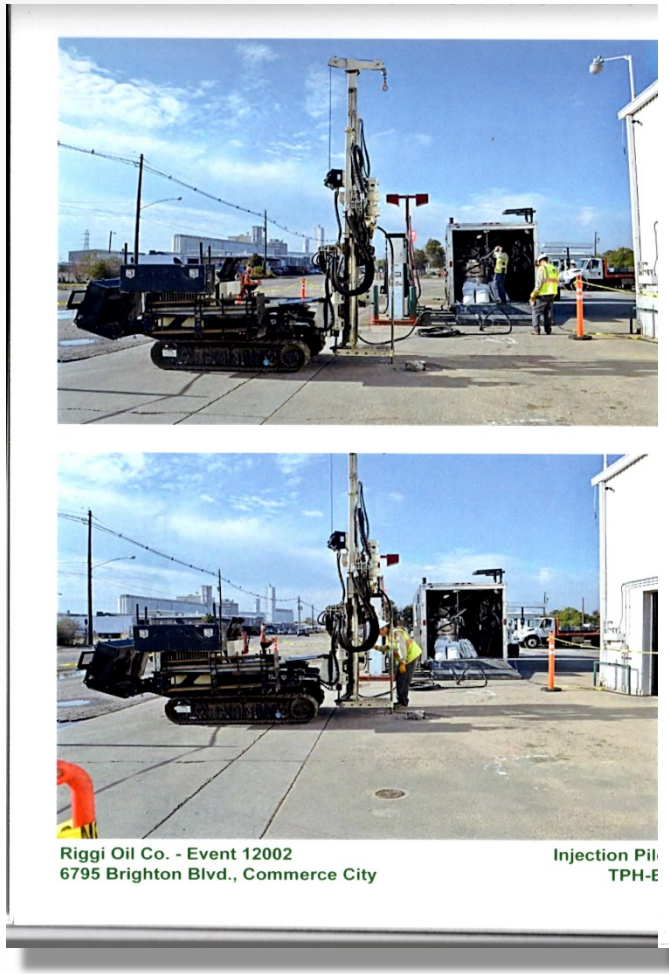
Parker Colorado – Remedial Strategy - Approach
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

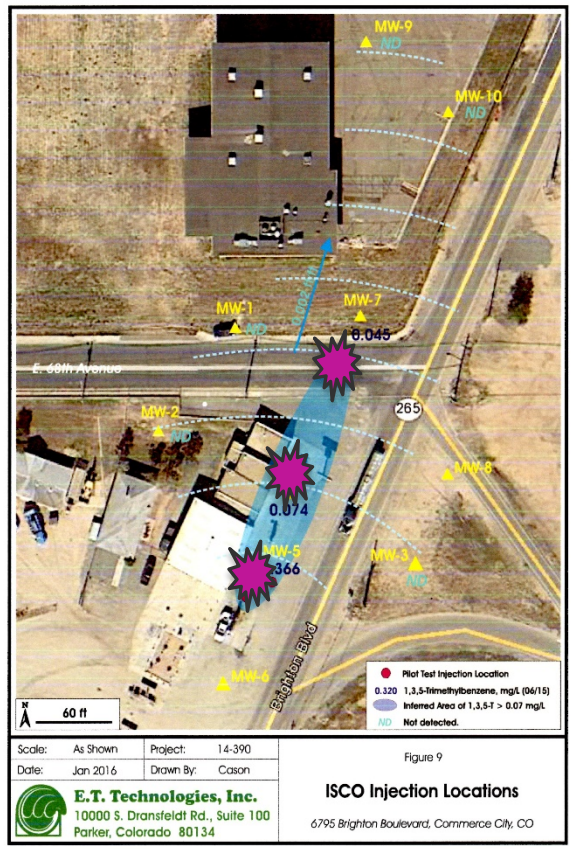
Baseline groundwater sampling performed June 2015

4 additional rounds performance monitoring and sampling performed September 2015 to June 2016.

June 2015 [1,3,5-TMB] in groundwater ranged from:

- ✓ 474 micrograms per Liter (µg/L) at MW5 (source)
- ✓ 168 µg/L at MW-4 (proximate center)
- ✓ 195 µg/L MW7 (off-site)





Parker Colorado – Bulk Tank Storage Facility
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

Treatability Evaluation Results

Downgradient Location MW-7

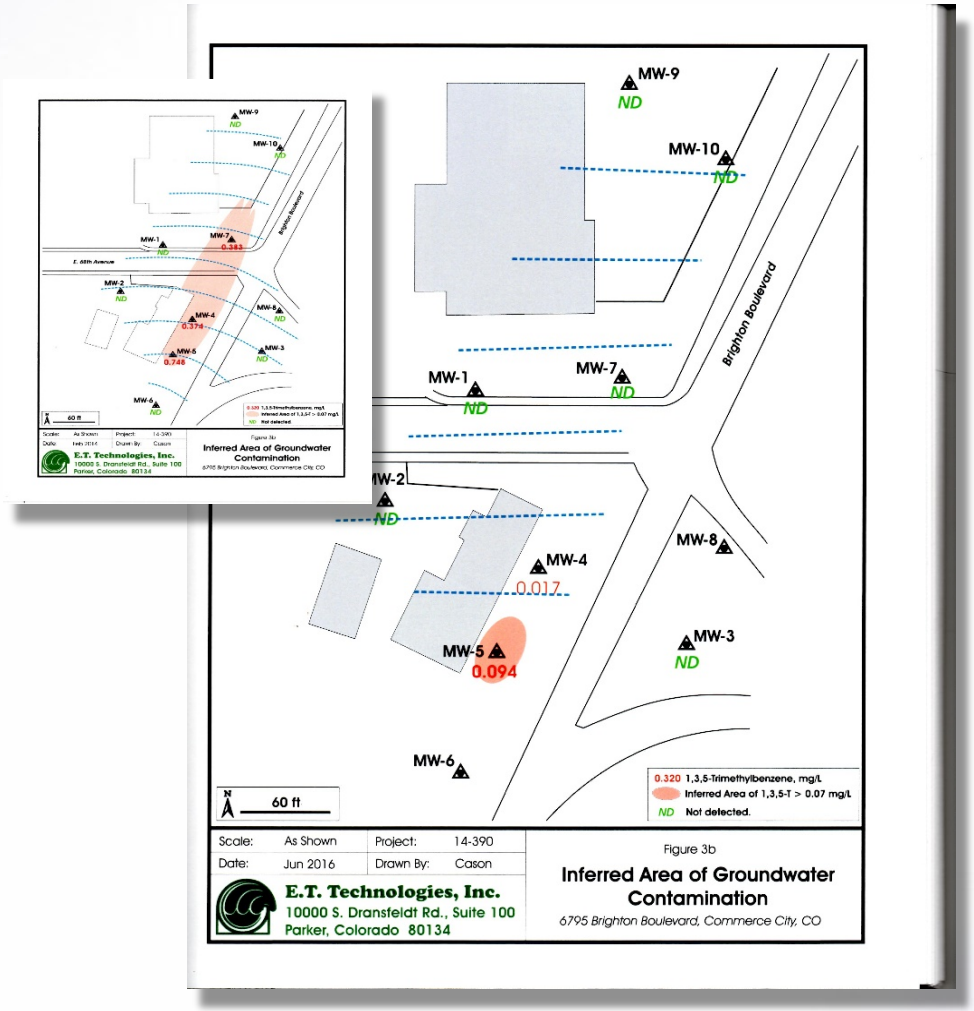
- >99.5% Overall reduction [1,3,5-TMB]

Mid Location MW-4

- 89.9% initial reduction
- Followed by 104% increase due to enhanced solubilization
- 76.9% reduction overall

Source Location MW-5

- 80.3% initial reduction
- Followed by 28.3% increase due to enhanced solubilization
- 83.5% reduction from peak bioavailability



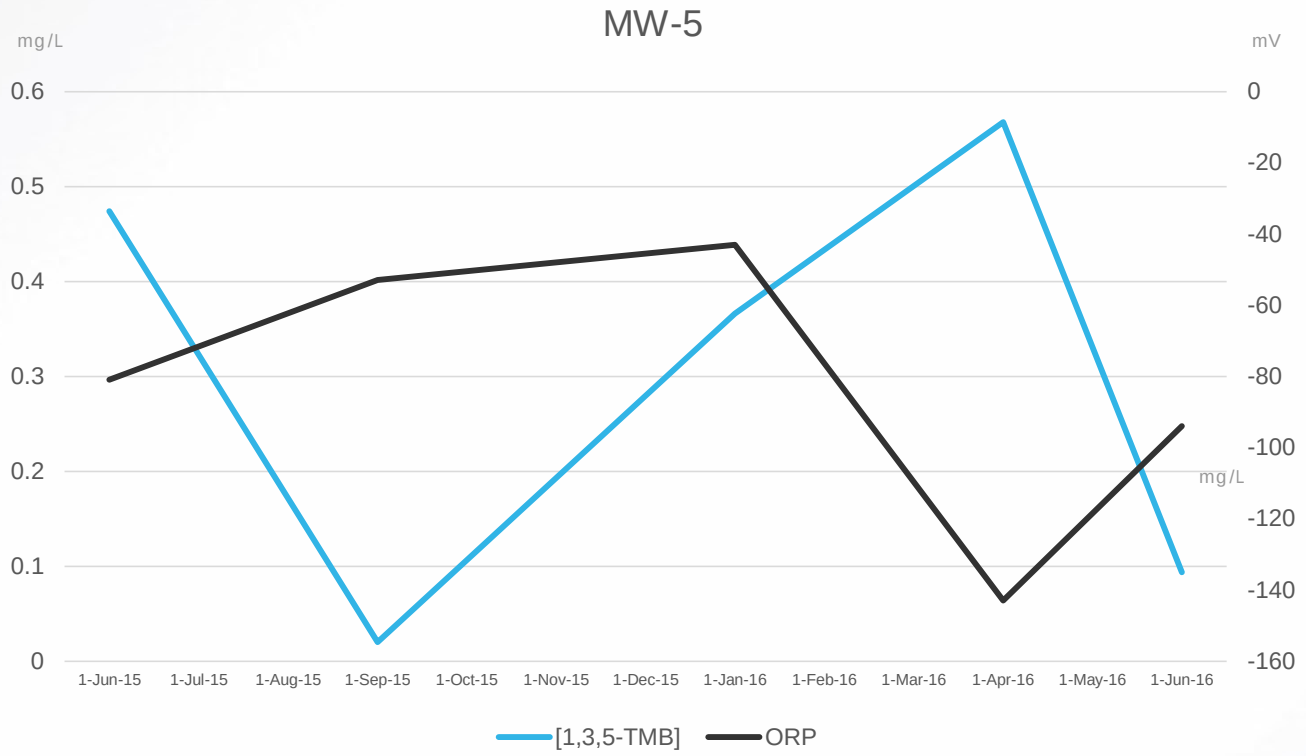
Parker Colorado – Bulk Tank Storage Facility
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

Treatability Evaluation Results

Source Location MW-5

- 80.3% initial reduction
- Followed by 283% increase due to enhanced solubilization
- 83.5% reduction from peak bioavailability

- ORP remained steady until [1,3,5-TMB] reached maximum bioavailability
- As bioavailability is increased and microbial populations are enhanced
- Expedited destruction of PHCs is realized

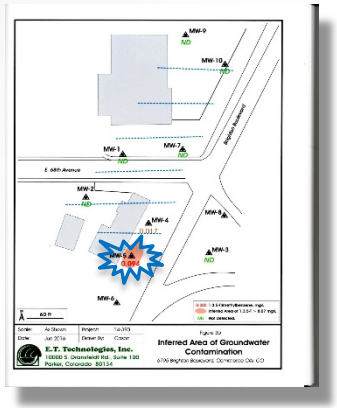


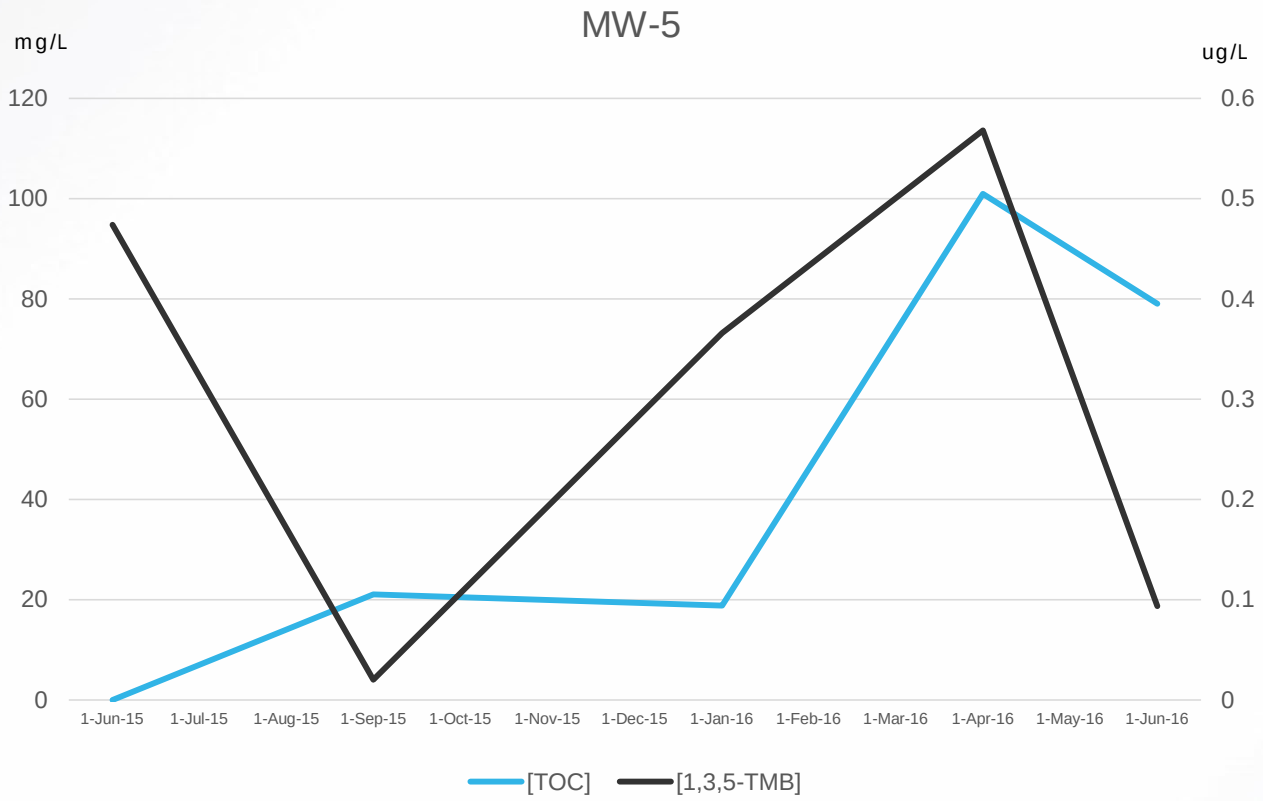
Parker Colorado – Bulk Tank Storage Facility
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

Treatability Evaluation Results

Source Location MW-5

- Initial dissolve phase destruction
- Followed by solubilization of organic mass; first [1,3,5-TMB], then native OC
- Once made bioavailable, both TOC and [1,3,5-TMB] decrease significantly
- **80.3% reduction** [1,3,5-TMB] from peak bioavailability





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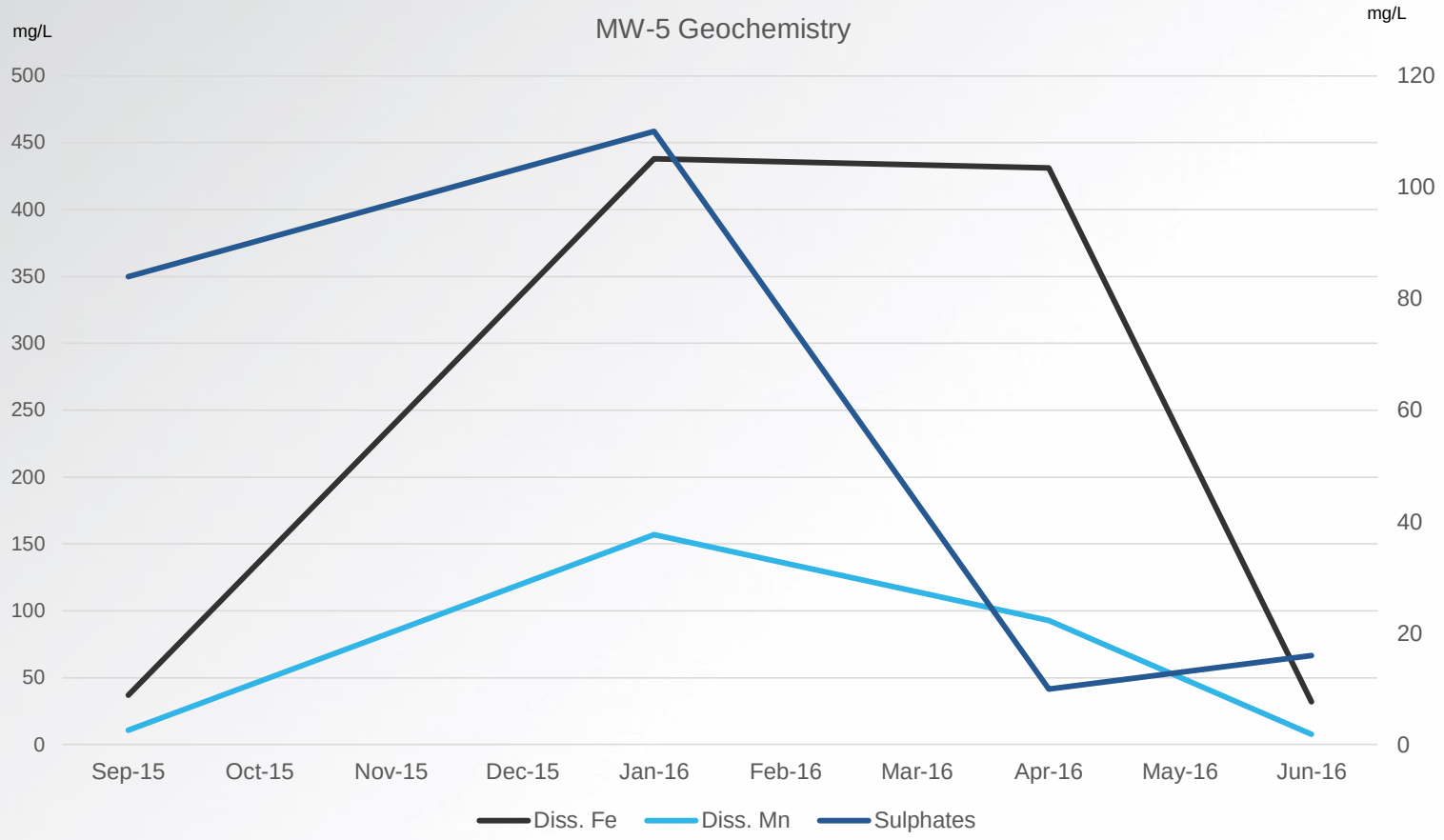
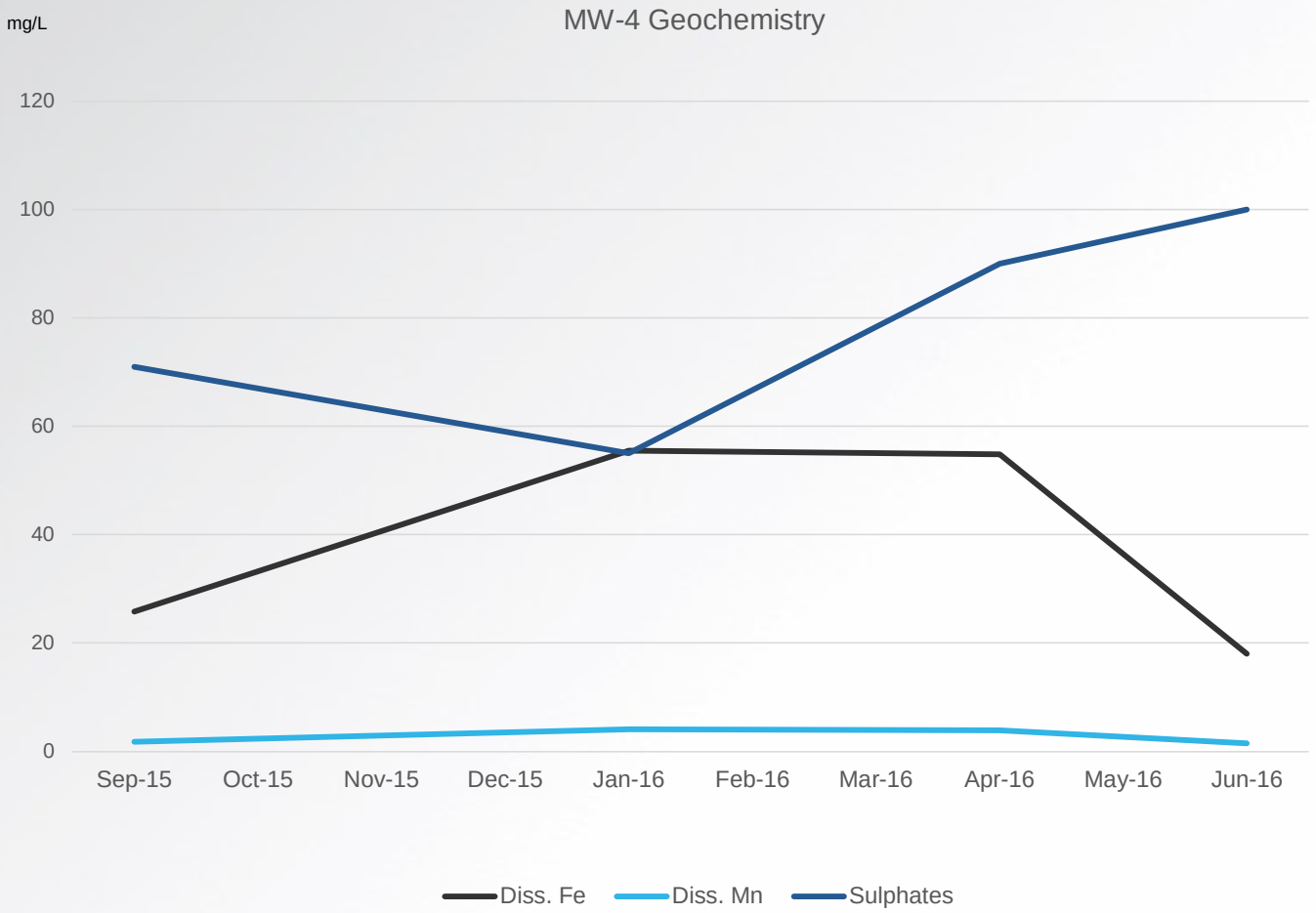


MW-5 Source Location Geochemistry

As influence of additive is realized

- Iron and Manganese respiration begins
- Sulphate respiration continues bit longer
- All depleted by month 9

Parker Colorado – Bulk Tank Storage Facility
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene



MW-4 Mid-Plume Location Geochemistry

As influence of additive is realized

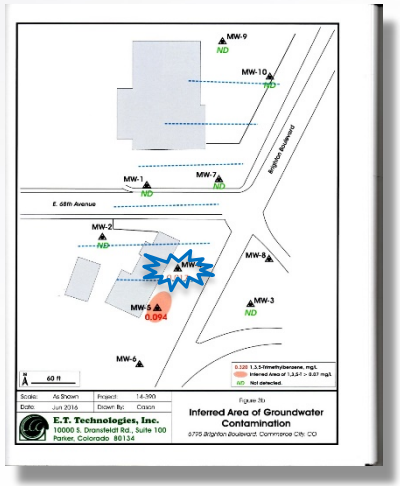
- Iron and Manganese respiration begins
- Sulphate respiration continues
- Fe/Mn approaching depletion

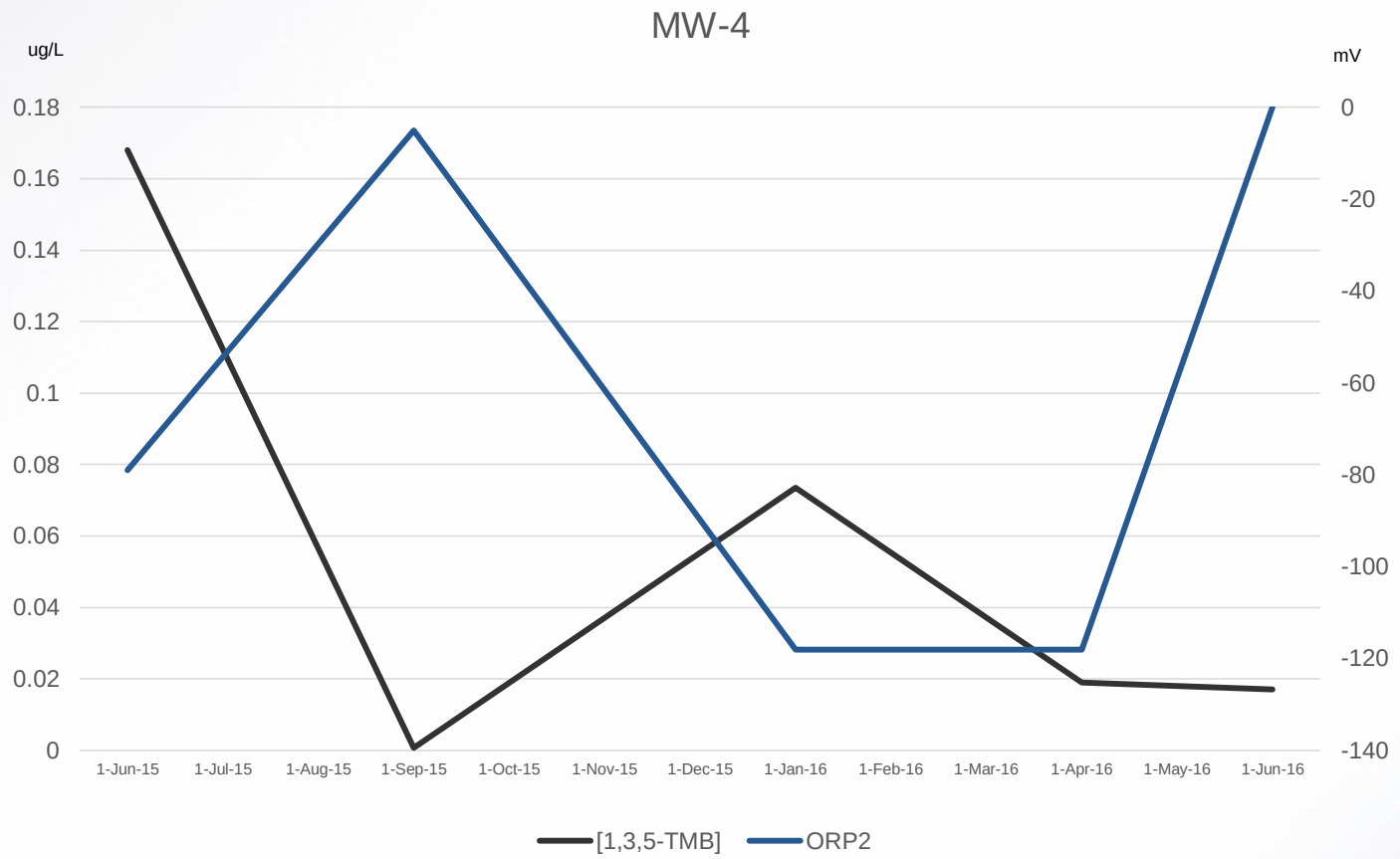
Parker Colorado – Bulk Tank Storage Facility
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

Treatability Evaluation Results

Mid Plume Location MW-4

- **89.9%** overall reduction [1,3,5-TMB]
- Initial dissolve phase destruction
- Followed by solubilization of organic mass; with decreasing ORP





Parker Colorado – Bulk Tank Storage Facility
TPHenhanced® Biostimulation for 1,3,5-Trimethybenzene

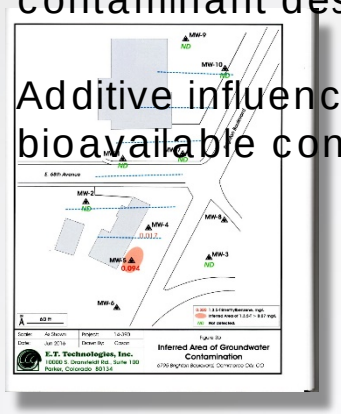
Off-site Location MW-7

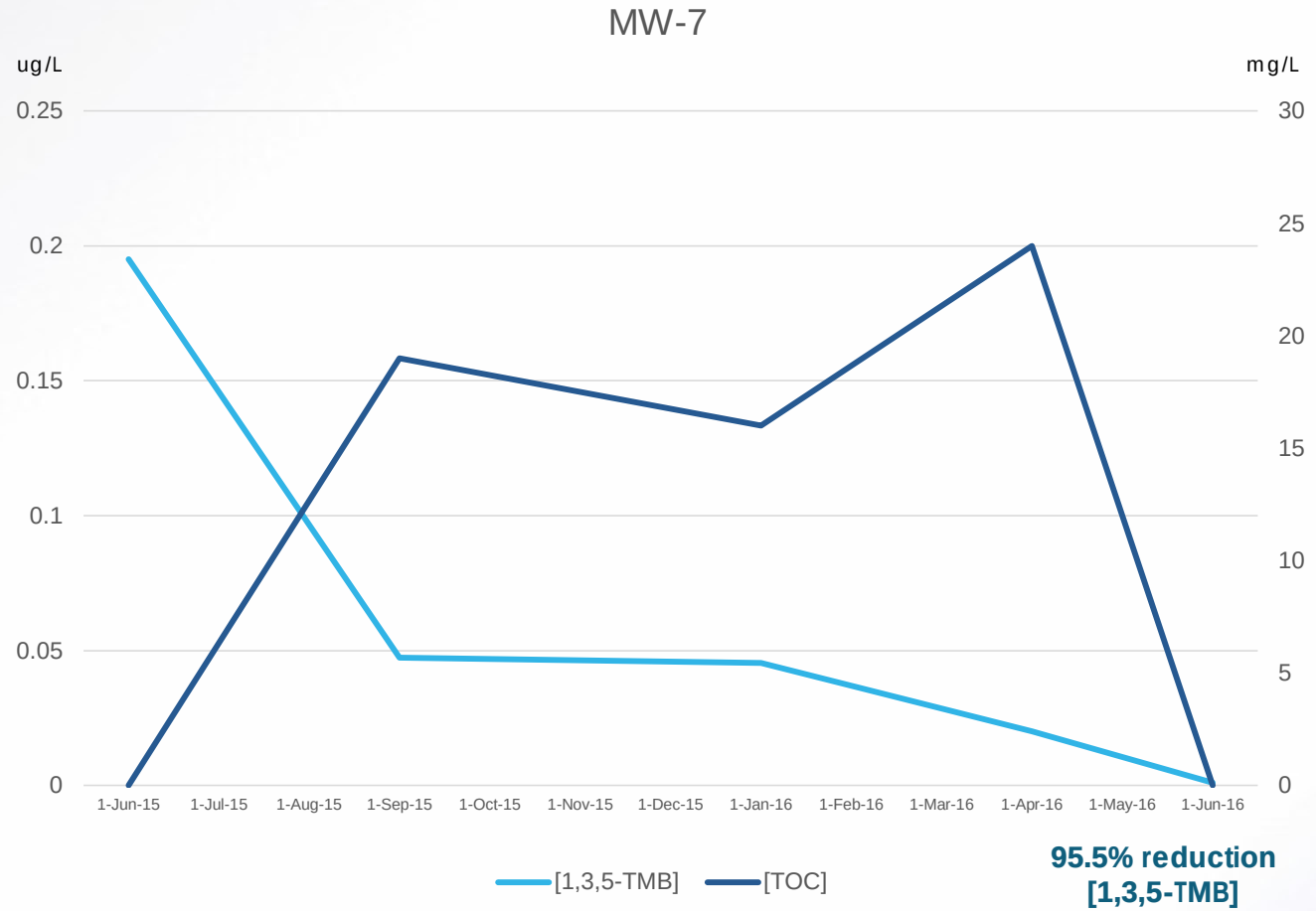
Observable increase then decrease in [TOC] With changes in ORP (-79, -5, -118, -118, NR)

Initial increase in ORP concurrent with increased [TOC], microbial populations also being enhanced

[TOC] steadies as a result of non-assimilatory contaminant destruction with solubilization

Additive influence increases and ORP rises - bioavailable contaminants are destroyed





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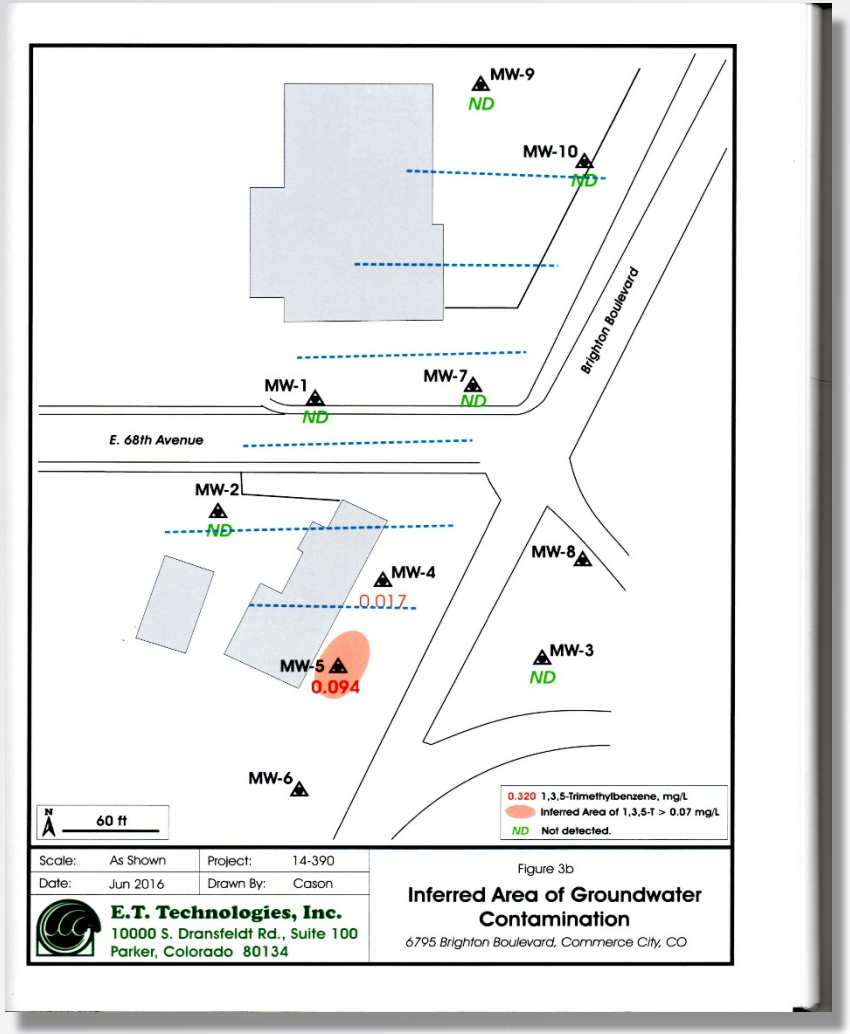
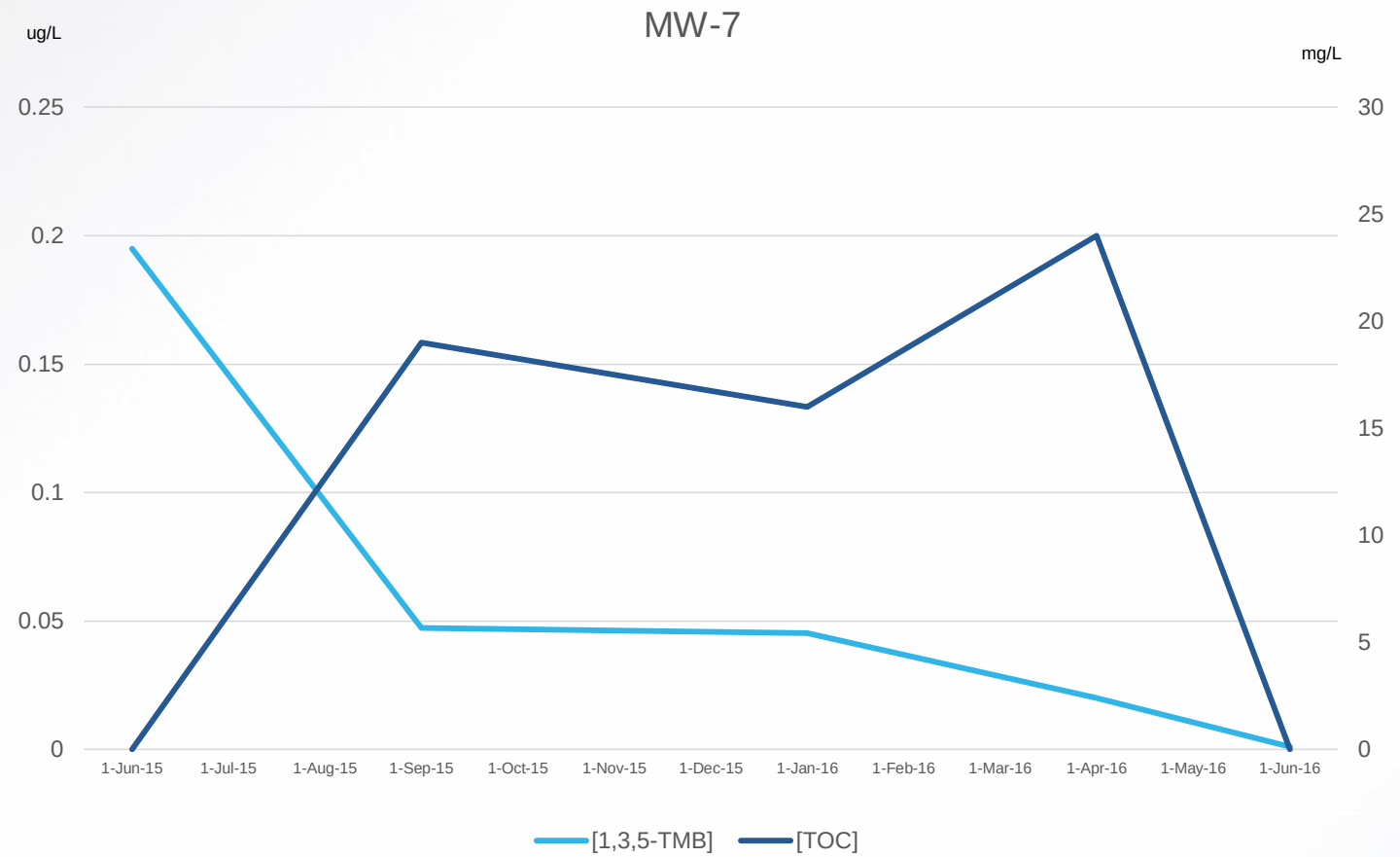




Contaminant Issues

Background – PHC/VOC/sVOC Contaminants

Dissolve Phase Groundwater Contaminants to include
Residual Source Mass in Saturated Soils

Typical Site Locations

Former Gas Service Stations
Abandoned Upstream Oil Facilities
Brownfield, Manufacturing and Production Facilities
Refineries, Pipelines, Bulk Tank Storage Facilities

Historical Limiting Site Conditions

Heavy Traffic/High Density to Remote Locations
Underground Utilities; Remote, Minimal Power Resources
Smear Zone Contaminants with Long-Term ‘Rebound’ Concerns

TERRA STRYKE

Who is TerraStryke®?
What can we do for YOU?

TerraStryke® Products LLC has been BioStryke Remediation Products LLC for past 7-years developing formulations that assist practitioners to

*I*ncrease project performance, *L*ower costs and *I*ncrease margins

TerraStryke® works to assist the establishment of 'Green' remediation strategies

And realize remediation objectives with minimal impacts

Proven products and strategies to achieve site remediation goals

safely, sustainably and effectively

Proof of Concept Evaluation ‘Drum Test’
Former Chanute USAFB Fire Training Area

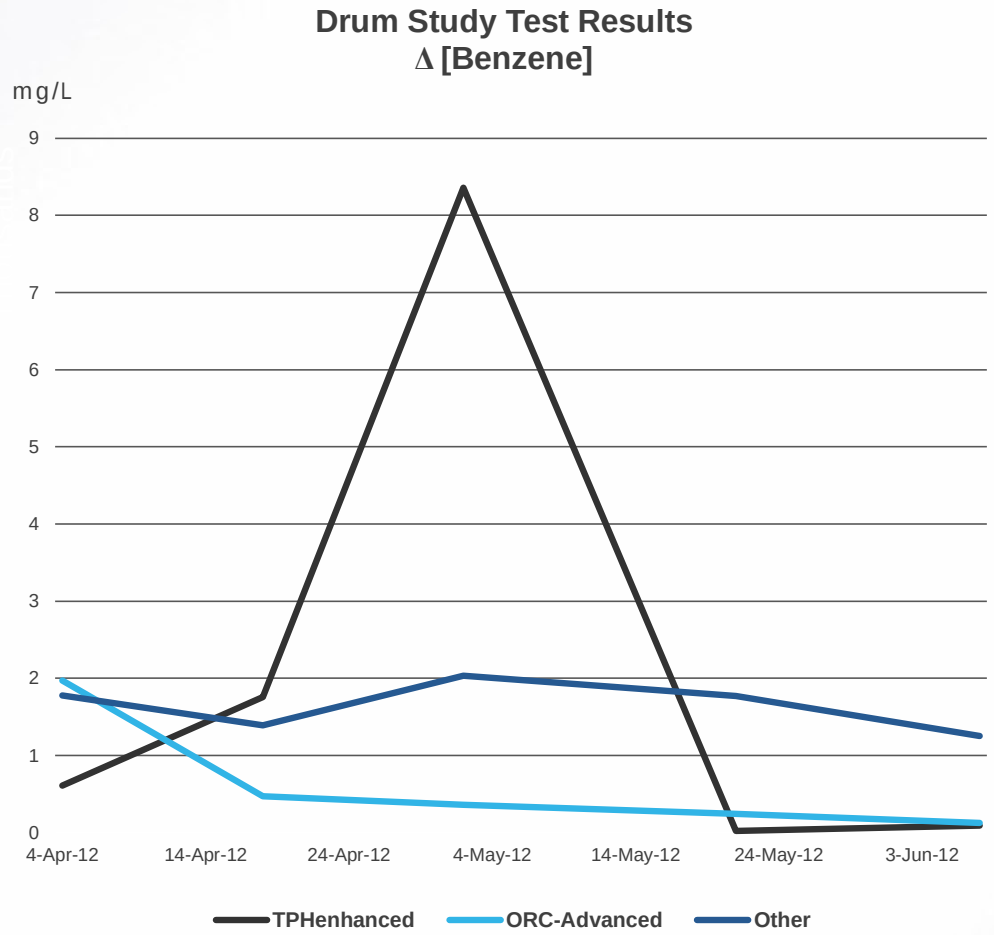
- **Initial Evaluation = ‘Drum-Test’**
- **Excavated Impacted Saturated Soils from Treatment Area Smear Zone**
- **Obtained Grab Sample of Saturated Soil From Excavator Bucket**
- **Place 1/3 of Grab Sample into 3 closed-top 55-gallon drums**
- **Filled Each Drum with Excavation Groundwater**

- **Consultant Amended each Drum According to Vendors Instructions**
  - **Drum 1 -** TPHenhanced® by TerraStryke
  - **Drum 2 -** Oxygen Release Agent
  - **Drum 3 –** Control
- **Dosing Rate Equal to that Established for Full Scale Deployment**

- **[PHCs] in** TPHenhanced® **amended drum**
  - **Decreased > 99% in 8-9 weeks**
  - **With Greater Molar Destruction**

Proof of Concept Evaluation ‘Drum Test’
Former Chanute USAFB Fire Training Area

- TPHENHANCED™ realized solubilization of contaminant
- Others did not
- pH differences significant
  - TPHENHANCED™ ranged 5.3-6.7su
  - Oxygen Release ranged 9.4-11su
- Results from 3 drums realized reductions [Benzene] ranging from ≈30% to ≈94%
  - Control 29.8%
  - TPHenhanced 84.8%
  - Oxygen Release 93.8%

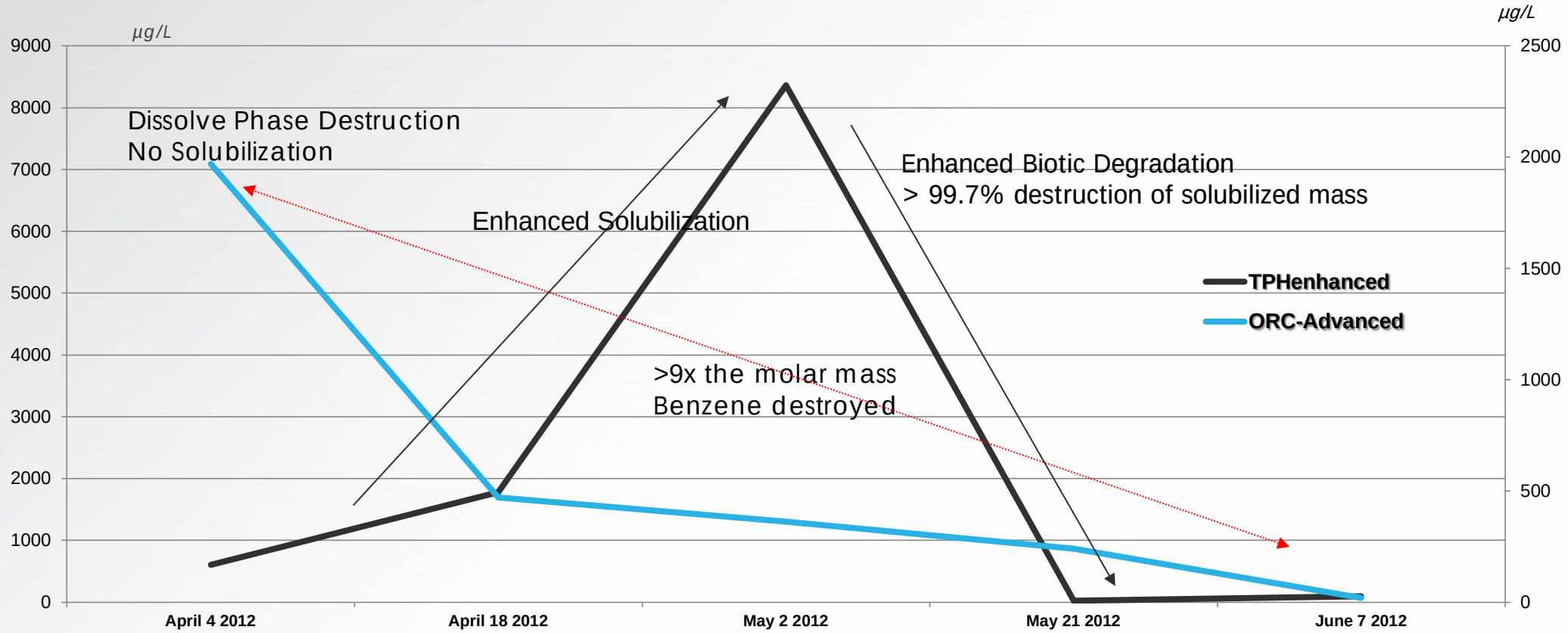


Drum Study – Results
Former Chanute USAFB Fire Training Area

TPHenhanced®	April 4 (µg/L)	April 18 (µg/L)	May 2 (µg/L)	May 21 (µg/L)	%Reduction
Benzene	606	1,780	8,350	24.6	99.7%
Naphthalene	197	178	302	2.02	99.3%
Toluene	2,360	3,620	8,370	13.4	99.8%
1,2,4-TMB	282	224	843	4.13	99.5%
pH	NT	5.7	5.3	6.1	NA

Oxygen Based	April 4 (µg/L)	April 18 (µg/L)	May 2 (µg/L)	May 21 (µg/L)	%Reduction
Benzene	1,970	471	362	241	87.8%
Naphthalene	213	76.7	34.1	8.36	96.1%
Toluene	6,320	1,130	651	385	93.9%
1,2,4-TMB	349	80.7	37.8	17.1	95.1%
pH	NT	9.4	9.8	10.3	11.0

TPHenhanced® vs. Oxygen Release Additive
[Benzene] Drum-Test Data



Enhance Long-Term Compliance

Summary Conclusions
TPHenhanced® Plotted Drum-Test Data

- Anaerobic drum groundwater realized:
  - Overall 84.8% reduction in [Benzene]
    - >1,200% increase [Benzene] 1st 4-weeks
    - 99.7% decrease [Benzene] from peak next week
    - Greater Molar Mass Destruction
  - Overall 89.8% decrease in [Naphthalene]
  - 99.3% maximum reduction from peak bioavailability
  - Overall 99.7% decrease in [Toluene]
  - 99.9% maximum reduction from peak bioavailability
    - Aerobic drum realized *NO* residual source mass solubilization
    - Anticipated 'rebound' in future as result

Based on drum test results the USAF Consultant chose TPHenhanced for full-scale application